JOURNAL OF HIGH-FREQUENCY COMMUNICATION TECHNOLOGIES
Vol. 01 (02) (2023), pp.64-72. ***e-ISSN:2836-9009***
https://doi.org/10.58399/KDHG4316

Design of Compact Dual Reconfigurable Antenna for WiMAX/WLAN Applications

Sangeetha Subbaraj[1*], **Anirudh E R**[2]

[1,2] School of Electronics Engineering, Vellore Institute of Technology, Vellore, India
E-mail address: sangeetha.s@vit.ac.in, anirudhe.r2018@vitstudent.ac.in

Abstract

In this manuscript, a compact dual reconfigurable monopole antenna is proposed. It operates at various frequencies depending upon the condition of the six operating conditions. The designed antenna exhibits dual reconfigurability, that is, frequency as well as pattern reconfigurability. This is done to increase the robustness of the proposed design. There are six lumped circuits in which each circuit consisting of two resistors, two capacitors and one diode. The antenna operates on the following resonant frequencies: 1.7 GHz, 2.45 GHz, 3.5 GHz and 5.2 GHz falling inside the application, such as WLAN and Wi-MAX ranges. This antenna due to its dual reconfigurability can be utilized in many areas, such as cognitive radio systems, mobile phones, etc. The reconfigurable antenna performance is examined under different states of diodes on the basis of the antenna parameters, such as return loss, radiation pattern and gain. The designed antenna exhibits dual reconfigurability; that is, frequency as well as pattern reconfigurability. The performance of the reconfigurable antenna under different states of diodes are examined.

Keywords: *Reconfigurable antennas; Dual reconfigurability; Frequency Reconfigurability; Pattern Reconfigurability; PIN diodes; WLAN; WiMAX*

1. Introduction

Owing to emerging trends in wireless communication, there is more demand of applications in the hand-held devices such as mobile phones, laptops and tablets. These services have wireless standards like Wireless LAN (2.4-2.48GHz), Wi-Fi (2.4 / 5 GHz), Bluetooth (2.4 GHz) and Wi-MAX applications (3.3 to5.8 GHz). Hence, there is an increasing attention in reconfigurable antennas (RA) for their effective use in portable devices with multiple wireless applications. Currently, theoretical and experimental efforts, have been carried out to enhance the performance provided by the reconfigurable antennas. To cover multiple services required by the user, various switching operations has been introduced into the antennas to facilitate the new requirement of the users. This can eliminate the requirement of the sophisticated filters in various antenna designs (Hinsz and Braaten, 2014). The discrete frequency switching and continuous tuning can be suitable for this aspect. However, frequency tuning has large accessible range than the switching operation (Petosa, 2012). Apart from the reconfiguration, other performance criteria, such as stability in the radiation characteristics, simple and low profile in design, external circuits for biasing are also plays a very important role while adopting it in modern portable devices, such as wearable gadgets,

[*]**Corresponding author**
Received: 21^{st}, February 2023, Revised: 28^{th} April, 2023, Accepted: 30^{th} May 2023 and available online 26^{th} June 2023

This work is licensed under a Creative Commons Attribution 4.0 License(CC BY 4.0).
For more information, see https://creativecommons.org/licenses/by/4.0/

portable devices, etc. (Ge and Luk, 2014). There are various methods of reconfiguration can be obtained based on the switching elements, i.e., optical reconfiguration, electrical reconfiguration and mechanical reconfiguration. This need to be examined to design a stable reconfigurable system for planar antennas in (Peroulis et al., 2005) & (Cetiner et al., 2010). Out of these techniques, faster switching period, less complex biasing mechanism, electrical tuning and high repeatability are generally preferred. The PIN diodes, RF MEMS and varactor diodes are mostly used as the tuning elements, and each of these methods of switching has its own merits and demerits (Petosa, 2012) & (Christodoulou et al., 2012).

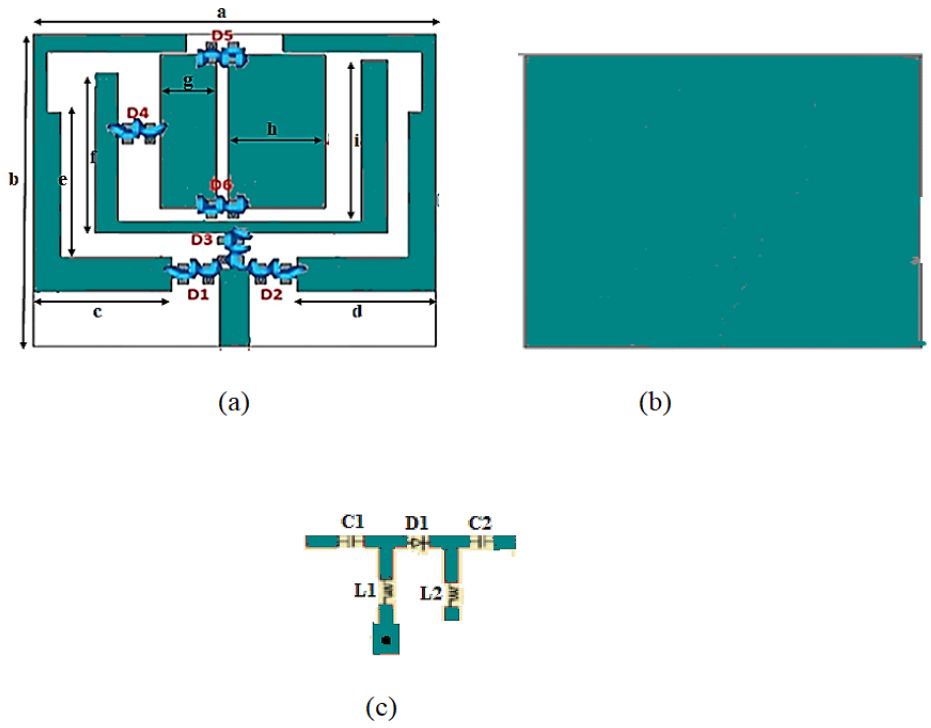

Figure 1. Design of the Proposed Antenna: a) Front view b) Back view c) Biasing circuit a= 40 mm , b= 40 mm , c= 15.2 mm , d = 15.2 mm , e = 29 mm , f= 20.6 mm, g= 6 mm , h=10 mm , i = 22.2 mm

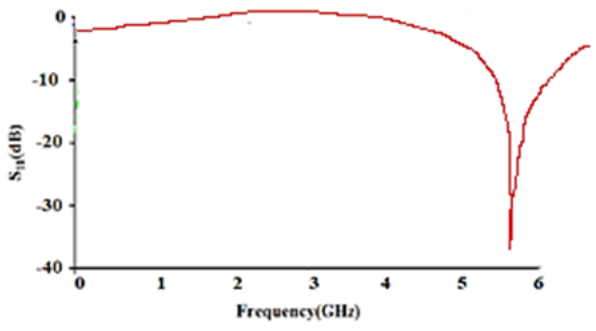

Figure 2. The State 1 of the antenna where D1 is in ON state

The geometry of the planar patch antenna has great significance for achieving reconfiguration. The other structures such as slot etched in the patches, parasitic elements coupled to the main radiator, nested radiators are investigated in (Erfani et al., 2012) & (Li et al., 2015b). Slotted structures offer more flexibility than the nested ones. The shape of the slot can be easily modified to make it to tune at the desired operating bands. These changes will not affect the structure of

the slot antenna and provides large tuning range as in (Yang and Rahmat-Samii, 2005). These techniques also help in reducing the size of the antenna. Based on the studies performed on the nested structures, it is seen that the dimensions of the patch antenna increase with the tuning range of the antenna (Li et al., 2015b) & (Nazir et al., 2016). In (Majid et al., 2013), the nine operating bands (1.98 GHz–3.59 GHz) achieved by the slot antenna are reconfigured. The discrete switching operation at two operating bands along with pattern reconfiguration is achieved in (Pazin and Leviatan, 2013). In (Li et al., 2010), continuous switching is introduced by the PIN diode and varactor diodes. This achieves the operating range from 0.42 GHz to 1.48 GHz with stable radiation characteristics in the entire range. Conversely, the biasing circuit for tuning the switching elements requires high voltage and is not suitable for some portable and wearable devices (Christodoulou et al., 2012). The slit-loaded planar antenna and slot antenna are investigated in (Xiao et al., 2003) for frequency reconfiguration range of 0.6 GHz. However, the number of switches used in the design is large and has limitations in the realization. In this manuscript, four operating bands are reconfigured along with the pattern reconfiguration. The antenna consists of a microstrip patch and a slot is etched at various positions of the patch. The patch produces a directional radiation pattern and it is tilted using switching mechanisms. The introduction of each slot has its own frequency of operation based on the length of the slot. In the proposed work, the frequency and pattern reconfiguration are achieved by simple configuration. The size of the antenna 40 × 40 mm and it operates for nearly six states. The manuscript is organized from Sections 1-4: In Section 2, the design of the proposed antenna is described and the results are discussed in Section 3.

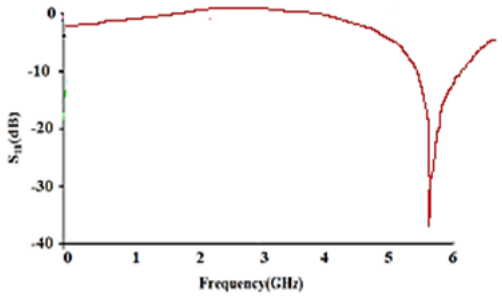

Figure 3. The State 2 of the antenna where D2 is in ON state

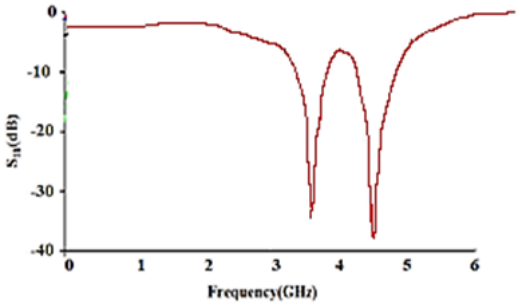

Figure 4. The State 3 of the antenna where D3 is in ON state

2. Design of Proposed Antenna

The proposed reconfigurable antenna is printed on an FR-4 substrate has dielectric constant of 4.3, thickness of 1.6mm and loss tangent of 0.02. The antenna is placed on the top of the metal display to accompany the other components. The supporting ground plane is of size 40mm × 40mm for better signal propagation. Antenna consists of radiators and a ground plane structure. The proposed antenna is a simple planar structure. The antenna operates as main radiator. The main radiator is sufficient for required signals, and then the wide frequency band is obtained

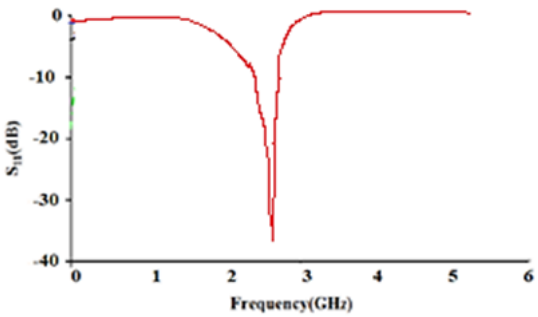

Figure 5. The State 4 of the antenna where D3 and D4 are in ON state

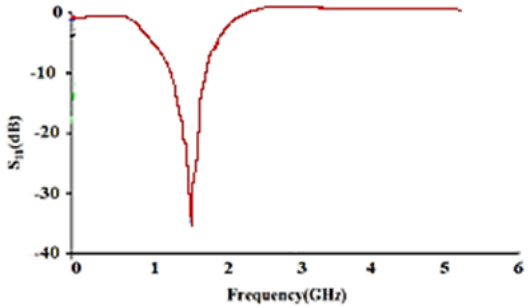

Figure 6. The State 5 of the antenna where D3, D4 and D5 are in ON state

from the aggregation of signals by the design. There is high proliferation of electric and magnetic field propagation in the antenna elements. The design incorporates frequency as well as pattern reconfigurability therefore it is named as "Dual Reconfigurability Antenna". Figure 1 shows the structure of the antenna; that is; its front view and back view with its dimensions marked in Fig. 1 and the lumped circuit consisting of capacitors, inductors, resistors and diodes are also marked. The blocking capacitor C1, C2 (20 pF) and RF choke inductor L1, L2 (33nH) are used. The BAR64-03W PIN diode is used for the switching purpose. During ON state of the diode, the value of resistance is 2.1 Ω and inductance is 1.8 nH. Similarly, during the OFF state of the diode, the value of shunt capacitance and resistance is 0.2 pF and 300 kΩ.

The antenna consists of two C-shaped structure on the right and left side of the feed, U-shaped structure and the patch. Initially, the C-shaped structure on the left side is connected to the feed line through the diode D1 as shown in Fig. 2. It resonates at 5.4 GHz corresponds to the length of the C-shaped structure. Similarly, the right-side C-shaped structure is connected through D2 achieves the resonant band at 5.4 GHz as depicted in Fig. 3. At 5.4 GHz, the antenna achieves pattern reconfiguration and frequency reconfiguration achieved in other operating bands. For the same frequency at 5.4 GHz, the pattern is tilted to the left side (D1 is on) and the pattern is tilted to the right side (D2 is on), respectively. When D3 is switched as shown in Fig. 4, the U-shaped structure is connected to the main feedline. This makes the antenna to resonate at 3.3 GHz and 4.5 GHz. These two resonances are due to the parallel resonance of the structure. The feed line is connected to both Patch and U-shaped structures through D3 and D4 as shown in Fig. 5.

This configuration makes the antenna to resonate at 2.6 GHz. Since the length is increased, the resonant frequency at 3.3 GHz is shifted to lower operating frequency at 2.6 GHz. Similarly, the resonance at 1.7 GHz is achieved by switching on the diode D3, D4 and D5 as depicted in Fig. 6. Similarly, by switching the diode D6, D4, D3, the resonance at 1.7 GHz can be achieved. The proposed system contains a compact multiband antenna system. It covers the multiple frequency bands, such as (1.7 -2GHz)/(2.4 -2.6 GHz) / (3.3-3.8 GHz) / (4.4-4.6 GHz)/(5.3-5.8 GHz) for LTE, GSM, WLAN, WiMAX and Wi-Fi applications.

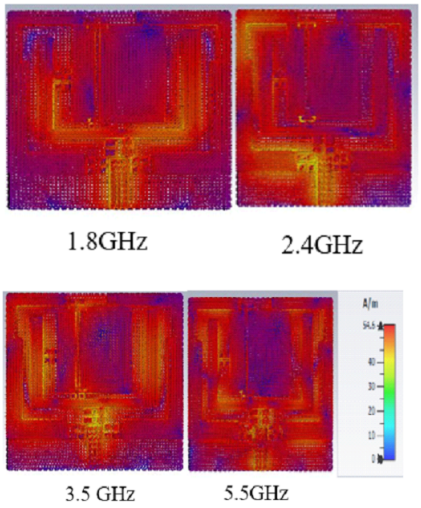

Figure 7. The surface current distribution of various operating bands

Table 1. Various States of Diodes

State	Diodes						Resonant Frequency (GHz)
	D1	D2	D3	D4	D5	D6	
1	ON	OFF	OFF	OFF	OFF	OFF	5.4
2	OFF	ON	OFF	OFF	OFF	OFF	5.4
3	OFF	OFF	ON	OFF	OFF	OFF	3.3, 4.5
4	OFF	OFF	ON	ON	OFF	OFF	2.6
5	OFF	OFF	ON	ON	ON	OFF	1.7
6	OFF	OFF	ON	ON	OFF	ON	1.7

Table 2. Efficiency and gain of the Proposed Antenna

Frequency (GHz)	Simulated Gain (dBi)	Measured Gain(dBi)	Efficiency (%)
1.8	3.080	2.9	72
2.4	3.177	3.02	78.8
3.5	3.596	3.234	79
5.5	4.823	4.56	85

The various operating bands of the diodes are listed in the Table 1. At 5.4 GHz, the pattern reconfigurability is achieved (+30° tilt and -30° tilt). The surface current distribution of the proposed antenna is shown in Fig. 7. At 5.5 GHz, the C-shaped structure on either side of the feed line is responsible for the operating band. At 2.4 GHz, the patch and U-shaped structures are responsible for the operating band. The two patches, U-shaped structure is responsible for the operating band at 1.8 GHz. Similarly, at 3.5 GHz is achieved by the U-shaped structures. The equivalent circuit model is shown in Fig. 8. The length of the corresponding resonant frequency is equated to the resistance and inductance value from the Smith chart. Therefore, for each state, the corresponding circuit is connected to the biasing lines. Hence, State 1 & 2 covers 5.4 GHz. State 3 covers 3.3 & 4.4 GHz. States 4 & 5 cover 2.6 and 1.7 GHz, respectively.

3. Results and Discussion

The fabricated antenna is tested for evaluating the performance of the antenna. The blocking capacitor C1, C2 (20 pF) and RF choke inductor L1, L2 (33nH) are used. The BAR64-03W PIN diode is used for the switching purpose. During ON state of the diode, the value of resistance is 2.1 Ω and inductance is 1.8 nH; similarly, during the OFF state of the diode, the values of

Table 3. Efficiency and gain of the Proposed Antenna

Work	**Size (mm)**	**Reconfiguration**	**Actuators**	**Gain(dBi)**	**Eff.** %	**Features**
(Majid et al., 2013)	50 × 50	Frequency	5 diodes	0.2-4.8	-	Frequency switching
(Nazir et al., 2016)	86.3 × 50	Frequency	3 diodes	0-1.12	-	Four operating bands, more complexity in switching
(Li et al., 2015b)	50 × 45	Frequency	4 diodes	0.97-2.34	63-70	Three operating bands
(Li et al., 2015a)	80 × 45.8	Pattern and frequency	5 switch	1.9-4.8	51-71	Two operating bands
(Ramli et al., 2015)	120 × 120	Pattern and frequency	12 switch	9-10	>90	Two operating bands
Proposed Antenna	40 × 40	Pattern and frequency	5 diodes	2.9-6	>70	More operating bands, less complex, better bandwidth and efficiency

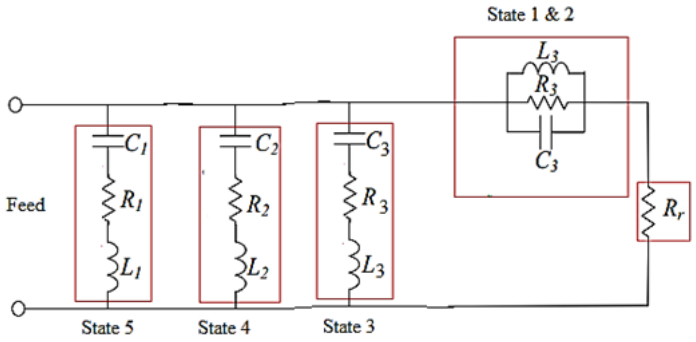

Figure 8. Equivalent Circuit Model of the Antenna

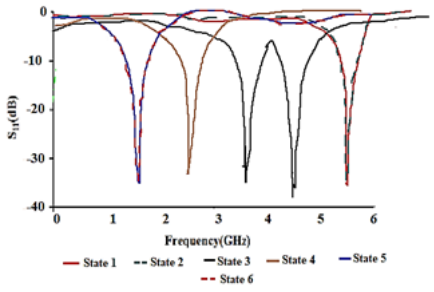

Figure 9. Measured reflection coefficient characteristics of the proposed antenna

shunt capacitance and resistance are 0.2 pF and 300 kΩ. The impedance characteristics at various operating states are depicted in Fig. 9. The measured results correlate well with the simulated results.

Similarly, the radiation characteristics (XY and XZ plane) of the antenna are measured at various operating frequencies, such as 1.7 GHz, 2.4 GHz, 3.5 GHz and 5.5 GHz. At 5.5 GHz, the

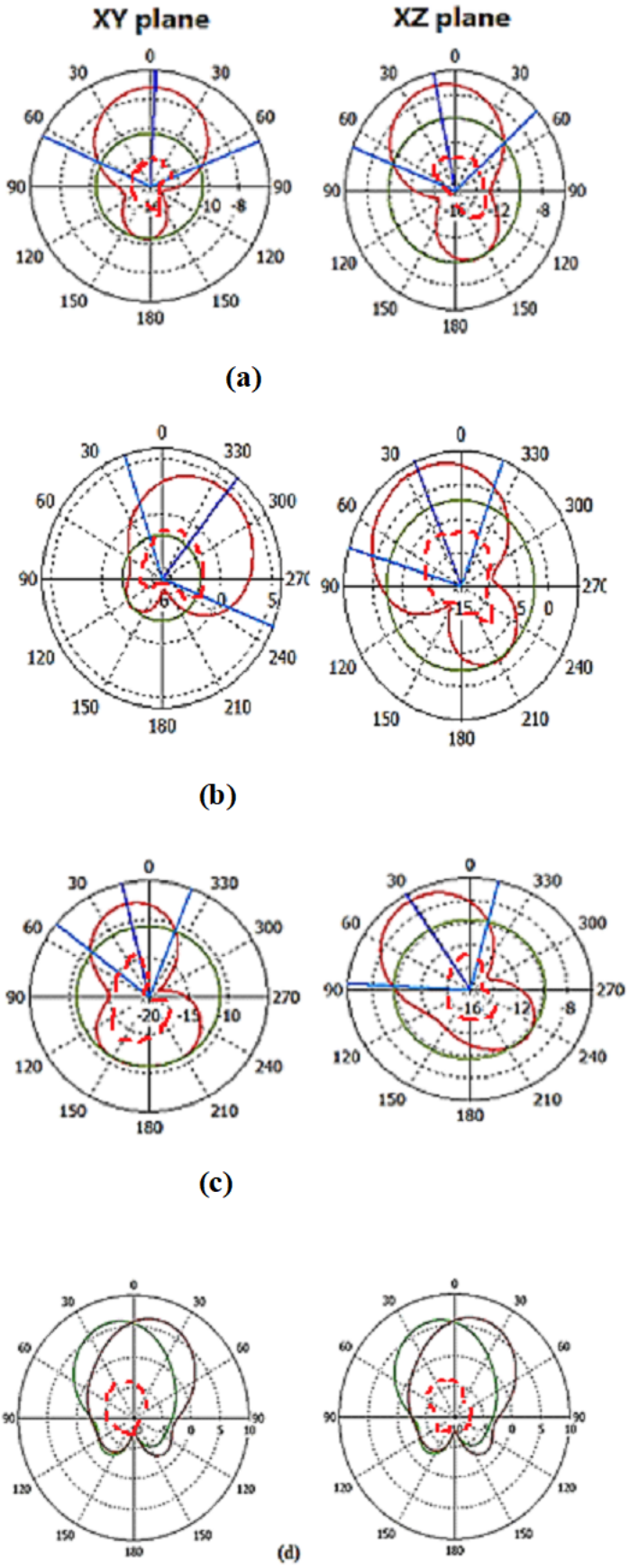

Figure 10. Measured radiation pattern (a) 1.7 GHz (b) 2.4 GHz (c) 3.5 GHz (d) 5.5 GHz (Green color-Diode D1 is ON, Red color- Diode D2 is ON, Dotted Red: Cross polarization)

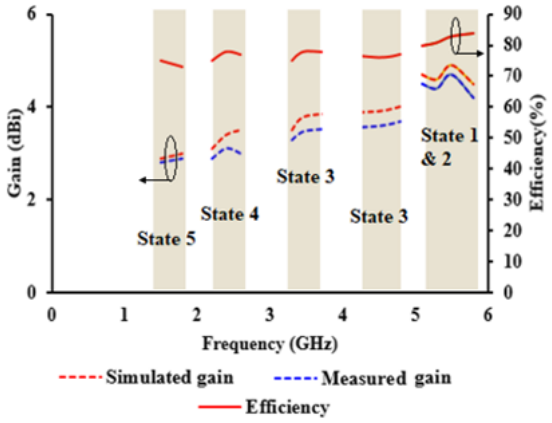

Figure 11. Gain and Efficiency of the proposed antenna

pattern reconfiguration is achieved as shown in Fig. 10.

The pattern tilt of +30° and -30° is achieved at 5.5 GHz. The directional plane is observed in all other operating bands. At the resonant frequencies 1.8, 2.4, 3.5, 5.5GHz, pattern observed in the azimuth plane (x-y plane) is directional. Similarly, the cross-polarization is less than co-polarization. The gain and efficiency are mentioned for the desired operating frequency as listed in Table 2 and also depicted in Fig. 11. The dual reconfigurability; that is, frequency and pattern reconfigurability are introduced to the antenna to increase the robustness of the antenna. The gain of the antenna is more than 3 dBi in all the desired operating bands. Similarly, the efficiency of the antenna is more than 70 % in the desired operating bands. The measured results and simulated results are correlates with each other. The proposed antenna is compared with other literature as shown in Table 3.

The salient features of the proposed antenna are as follows:

1. The proposed antenna has pattern and frequency reconfiguration for 5G applications
2. The antenna is low profile, small size and less complex.
3. For matching the impedance, additional circuitry is not required.
4. The gain and efficiency of the antenna is high in all the operating bands.
5. More number of bands is resonated by the small size of the antenna.

4. Conclusion

The design of simple dual reconfigurable antenna can be embedded in handheld devices. The dimensions of the proposed antenna are 40 mm × 40 mm and it is printed on a thin substrate. The multiple resonances are tuned with the help of switching elements. The proposed method does not have impact on the overall dimensions of the antenna. The four operating bands are reconfigured and it has six operating states. Radiation and surface current distribution of the antenna are analyzed. The S-parameter analysis is measured at various operating frequencies. The proposed antenna has simple configuration, low profile and more number of operating bands.

References

Cetiner, B. A; Crusats, G. R; Jofre, L, and Biyikli, N. Rf mems integrated frequency reconfigurable annular slot antenna. *IEEE Transactions on Antennas and Propagation*, 58, 2010. ISSN 0018926X. doi: 10.1109/TAP.2009.2039300.

Christodoulou, C. G; Tawk, Y; Lane, S. A, and Erwin, S. R. Reconfigurable antennas for wireless and space applications. volume 100, 2012. doi: 10.1109/JPROC.2012.2188249.

Erfani, E; Nourinia, J; Ghobadi, C; Niroo-Jazi, M, and Denidni, T. A. Design and implementation of an integrated uwb/reconfigurable-slot antenna for cognitive radio applications. *IEEE Antennas and Wireless Propagation Letters*, 11, 2012. ISSN 15361225. doi: 10.1109/LAWP.2011.2182631.

Ge, L and Luk, K. M. Frequency-reconfigurable low-profile circular monopolar patch antenna. *IEEE Transactions on Antennas and Propagation*, 62, 2014. ISSN 0018926X. doi: 10.1109/TAP.2014.2318077.

Hinsz, L and Braaten, B. D. A frequency reconfigurable transmitter antenna with autonomous switching capabilities. *IEEE Transactions on Antennas and Propagation*, 62, 2014. ISSN 0018926X. doi: 10.1109/TAP.2014.2316298.

Li, H; Xiong, J; Yu, Y, and He, S. A simple compact reconfigurable slot antenna with a very wide tuning range. *IEEE Transactions on Antennas and Propagation*, 58, 2010. ISSN 0018926X. doi: 10.1109/TAP.2010.2071347.

Li, P. K; Shao, Z. H; Wang, Q, and Cheng, Y. J. Frequency- and pattern-reconfigurable antenna for multistandard wireless applications. *IEEE Antennas and Wireless Propagation Letters*, 14, 2015a. ISSN 15361225. doi: 10.1109/LAWP.2014.2359196.

Li, T; Zhai, H; Wang, X; Li, L, and Liang, C. Frequency-reconfigurable bow-tie antenna for bluetooth, wimax, and wlan applications. *IEEE Antennas and Wireless Propagation Letters*, 14, 2015b. ISSN 15361225. doi: 10.1109/LAWP.2014.2359199.

Majid, H. A; Rahim, M. K. A; Hamid, M. R; Murad, N. A, and Ismail, M. F. Frequency-reconfigurable microstrip patch-slot antenna. *IEEE Antennas and Wireless Propagation Letters*, 12, 2013. ISSN 15361225. doi: 10.1109/LAWP.2013.2245293.

Nazir, I; Rana, I. E; ul Ain Mir, N, and Afreen, K. Design and analysis of a frequency reconfigurable microstrip patch antenna switching between four frequency bands. *Progress In Electromagnetics Research C*, 68, 2016. ISSN 15309681. doi: 10.2528/PIERC16052405.

Pazin, L and Leviatan, Y. Reconfigurable slot antenna for switchable multiband operation in a wide frequency range. *IEEE Antennas and Wireless Propagation Letters*, 12, 2013. ISSN 15361225. doi: 10.1109/LAWP.2013.2246855.

Peroulis, D; Sarabandi, K, and Katehi, L. P. Design of reconfigurable slot antennas. *IEEE Transactions on Antennas and Propagation*, 53, 2005. ISSN 0018926X. doi: 10.1109/TAP.2004.841339.

Petosa, A. An overview of tuning techniques for frequency-agile antennas. *IEEE Antennas and Propagation Magazine*, 54, 2012. ISSN 10459243. doi: 10.1109/MAP.2012.6348178.

Ramli, N; Ali, M. T; Islam, M. T; Yusof, A. L, and Muhamud-Kayat, S. Aperture-coupled frequency and patterns reconfigurable microstrip stacked array antenna. *IEEE Transactions on Antennas and Propagation*, 63, 2015. ISSN 0018926X. doi: 10.1109/TAP.2015.2388781.

Xiao, S; Wang, B. Z, and Yang, X. S. A novel frequency-reconfigurable patch antenna. *Microwave and Optical Technology Letters*, 36, 2003. ISSN 08952477. doi: 10.1002/mop.10746.

Yang, F and Rahmat-Samii, Y. Patch antennas with switchable slots (pass) in wireless communications: Concepts, designs, and applications. *IEEE Antennas and Propagation Magazine*, 47, 2005. ISSN 10459243. doi: 10.1109/MAP.2005.1487774.